AU/ACSC/WHITEHURST/AY-09

AIR COMMAND AND STAFF COLLEGE

AIR UNIVERSITY

THE SLIMEBALL:

THE DEVELOPMENT OF BROAD-SCALE MARITIME NON-LETHAL WEAPONRY

By

Daniel L. Whitehurst, Lieutenant Commander, United States Navy

A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

Instructor: Colonel Brett E. Morris

Maxwell Air Force Base, Alabama

April 2009

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
APR 2009	**N/A**	**-**

4. TITLE AND SUBTITLE
The Slimeball: The Development of Broad-Scale Maritime Non-Lethal Weaponry

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Command And Staff College Air University Maxwell Air Force Base, Alabama

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
To date, the development of non-lethal weapons (NLW) has concentrated on one-on-one applications and other small, tightly controlled situations. The development of broader scale NLW has lagged, however, even though the technical barriers to their employment do not appear to be insurmountable. In the maritime domain, in particular, making NLW available to decision makers could have decisive effects in a variety of potential and very real situations. The Slimeball is a two-part weapon system consisting of a floating sticky foam barrier that will resist attempts to remove it, and a submerged gel barrier that will impede movement through a ship channel. The parts can also be used independently of each other, depending on the type of munitions used to deliver the material and the desired effects. The primary consideration for successfully employing the system is to only use it in facilities that are sheltered from open water and exhibit restricted waterways, such as jetty-protected harbors or underground facilities with narrow adits. The individual components of the Slimeball already exist or can be manufactured to designers specifications, and some are even commercially available, but to date they have not been combined in the manner described here. By making a few key assumptions about the density and expansibility of the weapons components, it is possible to reasonably calculate the expected effects of individual Slimeball rounds of varying payload sizes, or of the combined effects of using more than one at a time. Additionally, the U.S.s existing inventory of munitions appears adequate for delivering the Slimeball to a variety of potential targets, eliminating the need for radical improvements in this arena even when standoff range and payload are taken into account.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**40**	

Disclaimer

Contents

Abstract

To date, the development of non-lethal weapons (NLW) has concentrated on one-on-one applications and other small, tightly controlled situations. The development of broader scale NLW has lagged, however, even though the technical barriers to their employment do not appear to be insurmountable. In the maritime domain, in particular, making NLW available to decision makers could have decisive effects in a variety of potential and very real situations.

"The Slimeball" is a two-part weapon system consisting of a floating sticky foam barrier that will resist attempts to remove it, and a submerged gel barrier that will impede movement through a ship channel. The parts can also be used independently of each other, depending on the type of munitions used to deliver the material and the desired effects. The primary consideration for successfully employing the system is to only use it in facilities that are sheltered from open water and exhibit restricted waterways, such as jetty-protected harbors or underground facilities with narrow adits.

The individual components of the Slimeball already exist or can be manufactured to designers' specifications, and some are even commercially available, but to date they have not been combined in the manner described here. By making a few key assumptions about the density and expansibility of the weapon's components, it is possible to reasonably calculate the expected effects of individual Slimeball rounds of varying payload sizes, or of the combined effects of using more than one at a time. Additionally, the U.S.'s existing inventory of munitions appears adequate for delivering the Slimeball to a variety of potential targets, eliminating the need for radical improvements in this arena even when standoff range and payload are taken into account.

To illustrate the utility of the proposed system, individual port facilities exhibiting a variety of sizes, levels of sophistication, incidental maritime traffic, and protection are considered, along with contemporary situations in which the system could potentially be deployed, including piracy, countering asymmetric maritime swarm tactics, and interdicting conventional fleet assets. Though not an exhaustive survey, these examples represent a broad sampling of real-world considerations that are likely to face contemporary decision makers and those in the near future. In terms of feasibility, advisability, deliverability, and applicability, the Slimeball can offer new and possibly vital options to decision makers in pursuit of our national interests.

Introduction

In accordance with our national interests, commitments, and responsibilities, America is constantly on watch on the frontiers of potential future conflict around the world. Every day, U.S. forces patrol potential hotspots and maintain a presence to ensure that any threat to our interests will not go unchallenged. Often the most visible element of this forward presence, and the force most likely to be in a position to respond to provocation should it arise, are the maritime forces of the U.S. Navy. Carrier Strike Groups (CSGs) and Expeditionary Strike Groups (ESGs), in addition to smaller elements of ships acting in surface action groups (SAGs) and even those operating independently, constantly prowl the waters of known trouble spots and potential flashpoints like the Persian Gulf, Gulf of Aden, and South China Sea, signaling American resolve and striking power and hopefully deterring any challenger.

Unfortunately, this has historically not prevented all provocations, due either to the inability of the fleet to be everywhere at once, or the challenger's belief that force could not be brought to bear against it for any of a variety of reasons. Recent examples of maritime provocations include the highly publicized capture of 15 British sailors by Iranian forces in the Northern Persian Gulf in 2007, the harassment of three U.S. Navy ships in the Strait of Hormuz by Iranian small boats in 2008, and the rash of piracy around the Horn of Africa throughout the decade, culminating in the capture of a supertanker and attempted raid of a passenger cruise ship in late 2008 off the coasts of Somalia and Yemen. In all of these examples, the aggressors took advantage of their ability to bring force to bear quickly on an unsuspecting target, or believed that they were unlikely to face effective retaliation, or both.

Thus, the question becomes how to address situations like these without escalating to a much broader conflict or appearing to preemptively resort to inappropriate levels of violence

against would-be attackers. An initial consideration could be the introduction of some substance into the water in advance of potential attackers that would alter the water's viscosity to, say, the consistency of tar, thus making headway impossible. While interesting, this did not overcome one of the limitations already acknowledged; that is, friendly forces cannot be everywhere. This might have been of use to the Navy ships in the Strait of Hormuz, but would not have helped the commercial vessels against pirates or the British sailors in their small boats conducting inspections. Also, assuming that such a capability could be developed, there is the inconvenient fact that ships at sea can simply maneuver around such an obstacle, and the ability of sea water to dissipate concentrations of nearly any substance due to its sheer volume. So, how then to introduce a persistent substance that could inhibit maneuverability, would resist removal, and would not tip the balance of hostility by resorting to conventional munitions and potentially touching off a much broader conflict? The solution was elusive until inspiration arrived from an unlikely source.

When in doubt, consult a doctor. Doctor Seuss, that is. In his book "Bartholomew and the Oobleck" a kingdom finds itself swamped and unable to function after it is inundated with a green, persistent, sticky slime. Further inquiries revealed that oobleck has become the accepted term for a simple mixture of cornstarch and water that exhibits both solid and liquid properties depending on how it is handled – low amounts of stress or shearing force leaves it in a liquefied state, while high amounts of stress temporarily solidify it. Fluids that behave in this manner belong to a family of substances called non-Newtonian fluids, which have a variety of commonly known and commercially valuable properties. Oobleck's primary characteristic, of getting thicker and more viscous when stressed, falls into the non-Newtonian category of rheopectic fluids, and this seemed to be a step towards solving the problem. Additional research suggested

that a combination of the effects available from existing commercial products, non-lethal weapon research, and no small amount of imagination could yield a workable approach to restricting maritime mobility.

Thesis and Methodology

The goal of the paper is to demonstrate that non-lethal weapons harnessing the properties of non-Newtonian fluids and chemical polymers can provide a unique and potentially decisive capability to U.S. forces in future maritime warfare. The concept that will be explored here is a two-part system known as "The Slimeball," which consists of a sticky foam-based floating surface barrier that resists efforts to remove it, paired with a chemical gel that restricts movement below the surface. Capitalizing on the novel properties of these substances will give the United States the means to mitigate risk and to counter potentially deadly threats in a variety of operational environments, particularly the maritime domain, without causing excessive casualties.

First, to lay the groundwork, the importance of the maritime domain to the Air Force's mission will be established, followed by a review of non-lethal weapons research and development to date. Then, the properties of several real and proposed substances will be examined that could be combined to make the Slimeball an effective maritime non-lethal weapon in specific employment situations. Following this, calculations will be presented to demonstrate the amount of materials that would be needed to have a decisive effect in three different situations: a small port facility sheltering mostly small littoral vessels; a larger commercial port that serves as home port for asymmetric small attack craft; and finally an underground port facility that supports regular naval vessels and capital ships. Each of these scenarios will be

accompanied by suggestions for weaponeering to deliver the Slimeball components and, hopefully, good results.

The Maritime Domain

In spite of the massive expansion of global communications, ever faster transportation, economic globalization, and exhortations that the world is somehow getting smaller, it is still two-thirds covered in water. As it has been since the founding of the nation, it is imperative that we defend our own unfettered access to the sea and ensure our freedom of action to uphold our economic and security interests wherever they may be. An estimated 90 percent of the world's cargo moves by ship, making defense of sea lines of communication (SLOCs) a critical component of defending the nation's economic well-being.[1] Additionally, due to the nature of the Navy's force posture, fleet assets are often the first that can reach emerging hotspots, and the routine deployment of ships to areas of critical concern is well established.

The sea is not the sole province of the Navy, however. Since it first demonstrated its power of observation and offensive strike capability in the early days of aviation, the Air Force has recognized the contributions that it can make in the maritime domain, and the development and delivery of maritime non-lethal weaponry is well within the Air Force's countersea mission area. According to AFDD 2-1.4, *Countersea Operations*, anti-surface ship operations and undersea operations are listed as collateral missions of the Air Force, thereby establishing the relevance and applicability of the non-lethal system described here.[2] It is also clear that the Air Force's ability to handle larger and greater amounts of ordnance, as well as the speed with which it can reach nearly any point on the globe could be the difference between success and failure of this concept, as will be illustrated in the coming sections.

NLW Imperative and Efforts to Date

Department of Defense (DoD) Directive 3000.3, issued in 1996, provides guidance for the development and employment of non-lethal weapons (NLW) and assigns the Commandant of the Marine Corps as the executive agent of the program. The expressed purpose of the directive was to provide commanders with additional options by providing them with weaponry that "employ means other than gross physical destruction to prevent the target from functioning" and that ideally have effects that are reversible on personnel or equipment.[3] Colloquially, this was to allow greater flexibility and to provide an option between "shouting and shooting." The directive was issued in response to the U.S. Marine Corps' and the U.S. Army's experiences during the withdrawal of U.S. troops from Somalia in 1995, in which commanders perceived a need for non-lethal capabilities and found their existing options limited.[4]

Since then, the focus of NLW development has largely been limited to relatively small-scale efforts and projects. The Joint Non-Lethal Weapons Program (JNLWP) website lists information on a variety of counter-personnel (CP) and counter-materiel (CM) systems, such as non-lethal grenades, bean bag projectiles, and physical arresting barriers that generally tend to one-on-one applications, or to localized situations like crowd control or restricting access at checkpoints.[5] However, the possibilities of NLW do not appear to have been sufficiently explored on a grander scale, involving the restriction or neutralization of men and materiel in anything much larger than a single vehicle or in environments beyond the terrestrial realm. This is in spite of admonitions from officialdom to pursue just such a capability, most notably a 2004 study from the Council on Foreign Relations urging the Air Force and Navy to devote more attention and resources to the development and employment of NLW, while simultaneously

advocating the development of precision delivery systems to increase the effective ranges at which NLW can be brought to bear.[6]

The most recent effort to apply NLW to the maritime domain came in November 2008, when the Joint Non-Lethal Weapons Directorate (JNLWD) was involved in testing and evaluating NLW in a ship-borne setting, in conjunction with the Navy, Marine Corps, Coast Guard, and elements from the Army in tests at Yorktown, Virginia. During a three-day battery of tests, NLW fired from shotguns and grenade launchers were tested, as were acoustic and optical devices designed to protect high-value assets at sea and aid in port defense.[7] Though these tests appear to recognize the importance of the maritime environment and the joint nature of defending it, the efforts are still very much in the realm of crew-served weapons in local situations at the tactical level of warfare.

The Slimeball concept elevates maritime NLW in scale and level of warfare, expanding the focus from countering individual aggressors to employing stand-off weaponry and affecting multiple vessels simultaneously. This approach is not entirely new, however, as many attempts have been made over the years to impede naval forces in a variety of manners, including floating smoke pots, entanglement devices, and even "floating purple mountains of shaving cream" to prevent or divert seaborne traffic, but none ever made it into wide use.[8] Cold War-era chemical weapons programs were designed to shut down enemy harbors using incapacitants, but have since been discontinued and were never used.[9] The point is that efforts along these lines, while coming across as a bit fantastic initially, have been studied and tested before and are technically feasible, but there is no indication in the background research that a concept identical to the one proposed here has ever been developed. It could also be the case that the time for such an application may have finally arrived, based on the post-Cold War 1996 guidance, and that what

seemed unrealistic or inappropriate when viewed through the potential superpower conflict of the Cold War may now be wholly applicable to the array of threats that the U.S. currently faces, in addition to those it will conceivably face in the coming decades.

Development of NLW for Use Against Maritime Targets

The primary problems in an open ocean environment are the relative ease with which vessels can simply alter course to avoid obstacles, and the effects of sea state, current, and the weather upon any material that is adrift; as a result, this generally puts a stop to serious discussion about physical barriers to movement before they even begin. If such a barrier could be placed into the restricted waters of a protected harbor or within a particular port facility, however, flexibility and maneuverability would be reduced or potentially removed altogether, and the effects of weather and sea state are mitigated. Therefore, the Slimeball is not a seagoing panacea, but is designed to be used against particular targets under particular circumstances. Any naval facility that depends on a narrow channel for access to the sea would be a natural target for this proposed system. Suitable targets would include harbors or basins that are protected by jetties, underground and/or covered facilities and even those that are positioned behind bridges or tunnels. Specific facilities representing a variety of real-world port characteristics will be discussed in a later section.

The Slimeball would consist of two principal parts: a floating foam barrier and a submerged gel barrier, which could be employed together or separately as the situation requires. Beginning with the **surface barrier**, the proposed material would need to drastically expand when released from its container (in this case, the weapon system used to employ it) and would combine additional properties, possibly including great viscosity, persistence, and stickiness. Thus, with the placement of a few bombs or missiles, a thick, sticky barrier could be placed in

such a manner that vessels are bottled up in port until the material evaporates or is removed. To date, I have not been able to discern the existence of a single substance that combines all these properties, although there are widely available materials that embody these characteristics singly.

The primary component of such a material would contain properties commonly found in shaving cream, due to its deliverability in a compressed state and high expansive capacity, estimated to be up to 850 percent of its compressed volume.[10] As commercially formulated, shaving cream is too insubstantial to create more than a nuisance to vessels, but in a denser form and combined with the chemical properties like those of a pre-existing substance known in defense circles as “sticky foam”, it would pose a far greater challenge for removal and have a greater dissuasive effect on vessels operating on the surface. Originally designed as an anti-personnel weapon, sticky foam has some significant drawbacks, including the risk of suffocation and the inability to transport the target due to the, well, stickiness of the material.[11] According to one estimate, each square inch of surface covered with sticky foam must be treated with baby oil for upwards of one minute in order to remove it, thus illustrating a major disadvantage of using it in an anti-personnel capacity.[12] Background research indicates numerous efforts towards developing various compositions of foam agents for niche applications, but none that entirely conforms to the desired specifications of the Slimeball concept. However, it has been suggested that due to the maturity of knowledge and development in this field, the drawbacks can be “engineered out,” and that the only requirement for fielding an effective foam-based system is for an agency to specify what characteristics should be tailored into it.[13] This statement, while highly encouraging, does not eliminate the need to keep the discussion within reasonable limits, which has hopefully focused the material in the following pages.

Thus, what properties would be present in the surface barrier of the Slimeball? The goal of the system is to impede movement to mitigate risks to friendly interests, not to permanently incapacitate personnel, materiel, or facilities. Ultimately, the optimum combinations of properties all require striking a delicate chemical balance: it needs to be sticky, persistent, and difficult to remove, but not to the highest possible level in any of these categories, lest it become permanent. It needs to cling to the surface of anything that attempts to cross it as well as to itself in order to have a cumulative effect on the vessel, "stacking up" upon itself as an object pushes through it and compounding the problem with its weight and negatively altering the handling characteristics of the vessel. Perhaps counter-intuitively, it needs to be formulated to dissipate in a set amount of time in order to allow normal activities to resume without potentially bearing the responsibility for lengthy and expensive cleanup operations. Even though the Slimeball is not meant to be a one-size-fits-all weapon, due to the unique characteristics of each potential target, it is not feasible or practical to recommend multiple formulations of the foam component. So, what follows is a recommendation of a single "formula" for the floating barrier, which can then be tailored to the specific situation only in the amount that is brought to bear on the target – less for smaller facilities or thinner barriers, and more for larger facilities or thicker, more persistent barriers.

In terms of stickiness, the "sticky foam" formulation appears to embody the extreme level of adherence to its target. Given the limited goals of the proposed system, though, this would seem to be greater than is needed to achieve the effect that is sought. A "less sticky than sticky foam" formulation is difficult to quantify, however. Precise definitions are hard to come by, and even in one of the seminal works on the subject, sticky foam is said to have "an adhesive tensile strength about an order of magnitude greater than common sticky materials such as molasses,"[14]

which clearly does not easily translate into a numerical value. There does not appear to be a universally accepted scale of stickiness; rather, measurements taken in fields where stickiness is an issue (textiles, food manufacturing, genetics, and others) tend to be specific to the field instead of conforming to a single scale, like the Mohs scale of hardness, for example. Without such a yardstick, then, it seems reasonable to focus on the types of material to which the foaming agent will adhere. For example, it may be possible to engineer the foam to adhere more strongly to wood, metal, and masonry than to skin or fabrics, making it far more of a nuisance to ships and structures than to the people in the area and thereby reducing the potential hazard to human life through suffocation. It will be up to the chemists and their laboratories to translate these desired characteristics into a workable solution, but there is ample reason to believe that such a material can be developed, even in the absence of a numerical, easily quantifiable goal.

Persistence is an area that shows strong promise for precisely determining and engineering a pre-designated period of time for the material to linger in the environment. Other foam-based NLW concepts and prototypes have involved materials that simply evaporated after a certain period of time, although they were water-based and designed for use on land, and thus were easily isolated from water to regenerate themselves.[15] In the maritime environment, then, it would make more sense to use a non-water based foam to ensure that it will "shut off" rather than be continually replenished by an unlimited amount of seawater. This will rule out the use of aqueous foam applications, which as the name implies depend on water as a primary component. However, this limitation is not a devastating one, as aqueous foams tend to be much lighter and insubstantial that those derived from other chemicals and tend to have the consistency of soap bubbles, which would not appear to be robust enough to accomplish the task at hand. One study showed an impressive 500 to 1 expansion of such a material, but indicated that it could be

effectively removed by compressed air, water spray, or even with a simple carbon dioxide fire extinguisher.[16] Previous attempts to manipulate the persistence of foams to increase the so-called "drain time" have found that ingredients like sugar and glycerin can offer significant effects in stability and thickening, and that sugar has the added benefit of altering the stickiness of the final compound.[17] The obvious component of seawater that could be exploited to break down the foam over time is salt – if a chemical base for the foam that gradually deteriorated in the presence of salt could be employed, this would appear to solve the issue of persistence. The effect of salt on foam persistence has been an area of previous research, and it is known that "salt concentrations play a crucial role in determining whether a foam will collapse."[18]

If it became clear to the targeted facility that salt water was the key to unlocking the foam's grip on its structures and ships, then it would be a simple matter of dousing the foam with salt water to remove it – in fact, any of the previously mentioned methods (compressed air, water spray, or some chemical means like a fire extinguisher) appear to be obvious methods that the victim of a Slimeball attack would use to rid itself of the weapon's effects. In anticipation of this, another property should be engineered into the foam in order to make its removal difficult by physical means, and the use of the aforementioned rheopectic fluids may be an effective means to this end. A rheopectic substance becomes thicker and more viscous when it is stressed, meaning that a foam impregnated with rheopectic fluid would resist attempts to remove it. Spraying it with water might have some impact, but the force of the spray would cause the foam to "set up" and become firmer, which would make the water bounce off of it like it would any hard surface. It would also confound attempts to forcefully push it away or scrape it off, and while sufficient manpower and effort would surely yield some progress, it should become apparent to the targeted facility that its best strategy would be to wait for the material to dissipate

on its own, either through the effects of the waves and current, or as a result of the planned deterioration that was engineered into it. Rheopectic fluids are somewhat rare, and include some lubricants and inks.[19] However, rheopectic properties should be achievable as part of the engineering process, as long as the requirements are clearly laid out.

It may seem a tall order to specify so many requirements into a single foam application, but no single element of the proposed design is new or radically different from pre-existing materials. Rather, it is a matter of combining all the desired properties into a deliverable product. Calculations regarding how much foam would be necessary to impede movement in various sizes and types of facilities will follow in the following section.

In addition to impeding vessels on the surface, it may be desirable to impact **sub-surface** mobility as well. This feature of the Slimeball presents fewer challenges from a chemical engineering standpoint, but is not without difficulties. Underwater mobility can be impacted with the addition of polyacrylamides (PAM), a commercially-available flocculating agent that forms a semi-solid gel in the presence of water. This material is widely available for numerous commercial applications from waste management to horticulture to baby diapers. By some estimates, it can absorb one thousand times its volume in water, though the chemical composition of the water, along with presence of dissolved and suspended solids, can greatly affect the rate of absorption. Thus, in seawater, which has fairly high concentrations of impurities, this absorption factor can be expected to decrease to a factor closer to two hundred.[20] Additionally, the gel is neutrally buoyant, meaning that it is just as likely to sink as float, and therefore must be present in enough quantity to physically fill the submerged space to have a chance of being effective.[21]

The larger challenge with the submerged PAM barrier is keeping it in place and delivering it in such a manner that it will have the desired effect. PAM forms globs in the presence of fluids, but as commercially employed, usually the fluid runs out before the PAM does. There comes a point where the chemical agent will be overwhelmed by the amount of fluid and will not exhibit much of an effect – this would surely be the case in a maritime environment. Drums full of PAM could be dumped into the sea, and even though it would indeed absorb a proportional amount of seawater, it would have little effect unless it could be contained and held in place; otherwise, it will simply drift away, having about as much impact as the proverbial drop in the ocean.

Greater attention will be given to the mathematical determination of how much PAM would be needed to have an impact on particular facilities in the next two sections; in this section, however, the question revolves on how to hold the Slimeball together and in place. Flocculating agents are typically available as powdery crystals, which are very stable and easy to handle and should present no particular challenge in delivery to a target. It appears that the most direct method of holding the material together during and after the absorption process is not to alter it chemically or impregnate it with some form of coagulant, but to physically enclose it. To this end, a water-permeable membrane would need to be fashioned into a bag, for lack of a better word for it, which could contain the crystals and expand with them while they swelled up. Here again, commercially-available materials come to mind, including spandex, nylon, and even "boil-in-bags" commonly used in food preparation.

Once this problem is solved, attention must be given to holding the bag in place. Any system used to deliver a Slimeball would need to incorporate some mechanism capable of fastening the subsurface portion to the sea floor, or at least of anchoring it until it gained enough

mass as part of the absorption process to resist whatever current might be present at the target site. While some mechanical means of "spiking" the bag may be available, it seems that some or all of the body of the delivery method might be utilizable for this purpose. Since the Slimeball is not an explosive, the actual body of the delivery system should remain largely intact.

Though the Slimeball concept envisions using the surface and subsurface capabilities in tandem, it is conceivable that they could be employed separately as well. If a determination were made that one or the other half would be most effective in a particular situation, then it seems prudent to make the choice available to mission planners. Therefore, in the following section, calculations will be made using the assumption that the Slimeball's component parts can be delivered separately, and therefore that they will not be necessarily be present in the same munition.

Thus, a clearer vision of the proposed system emerges. The surface portion will use a chemical-based foam substance that incorporates strong adhesive properties, is resistant to removal by physical means, and is designed to gradually break down through a combination of extant forces, including evaporation and interaction with seawater. The subsurface portion will predominantly use the commercially-available material known as polyacrylamide (PAM), which will be contained in a water-permeable bag that can hold the material in place and expand along with it while it absorbs seawater to form a physical barrier to movement. With these characteristics in mind, it is now necessary to calculate how much could be delivered and what effect should be expected through introducing these materials into a given environment.

Delivery of the Slimeball's Components

Devising the active component of any weapon system is only half of the problem. Ultimately, the weapon must be delivered to the target and placed accurately for there to be the

desired effect. Here, pre-existing delivery platforms will be considered to simplify matters, though it is possible to posit an entirely new system to maximize the effects; however, that is beyond the scope of this project.

Assumptions

Several assumptions had to be made in order to arrive at the following calculations. First, since the density of the foam mixture that will be used in the surface component of the Slimeball is unknown until it can be satisfactorily developed in a laboratory, calculations have been made using the density of water. This is not an unreasonable assumption, since it allows for the easy metric conversions and is based on an unscientific but simple observation – that is, shaving cream in an 11 ounce steel can weighs approximately the same as a beverage in a 12 ounce aluminum can. There is bound to be some variance between the forthcoming calculations and what could be expected in real-world applications, but these numbers can at least provide a starting point for development. Second, the factor of expansion in the foam is assumed to be approximately 100 times its condensed volume, and for PAM is 200 times its volume. According to Kenneth Collins, a project manager and chemist at the Aberdeen Proving Grounds, this foam expansion is reasonable and thick enough to present a barrier with the desired characteristics.[22] Likewise, the PAM expansion factor of 200 is a reasonable estimation, and is far less than the factor of 1,000 that some manufacturers promise, due to the presence of dissolved solids in seawater. Additional research and development could yield better materials with greater expansion rates, but for the purposes of this paper those factors will be used. Third, the desired size of the subsurface portion of the Slimeball is described roughly by a sphere 10 meters across. This number reflects an approximation of the depth of the water in an average port; thus, a 10 meter sphere would fill most of the space from the surface of the water to the sea

floor. Finally, the desired size of the foam barrier disseminated by each of the delivery methods is 50 meters wide, 10 meters across, and half a meter thick, for a total of 250 cubic meters of foam. Of course, it is impossible to deliver a perfect rectangle of uniform thickness using air-to-surface ordnance, but even with variations these dimensions appear adequate to have an effect on the facilities for which the system was designed, which will be further developed in a later section.

Delivery Method 1: AGM-154A Joint Standoff Weapon (JSOW)

The JSOW appears to be a logical candidate to employ the surface portion of the Slimeball due to its employment of BLU-97 bomblets, which are designed to scatter over a wide area. The JSOW has a standoff range of between 12 and 63 miles, depending on its release altitude, potentially negating any concerns that may exist regarding whether or not friendly forces have air supremacy and can operate without fear of engagement by enemy air defenses. Additionally, it is employable by nearly all of the Air Force's fighter and bomber platforms, giving it high marks for flexibility.[23]

Mathematically, though, it is limited. Each JSOW carries 145 of the BLU-97 bomblets, which measure approximately 20 centimeters high and 6 centimeters across.[24] Using the standard calculation for volume [(pi)(radius, squared)(height)] and assuming that the full volume of each canister could be filled with the foaming agent, each bomblet can hold approximately 565 cubic centimeters of material. Multiplied by 145, a single JSOW's best possible volume is just under 82,000 cubic centimeters of foaming agent, and this is probably generous considering that each bomblet has internal mechanisms that offset the volume of material that could be carried. However, using the absolute best case scenario, and assuming expansion of each JSOW's contents to 100 times its original volume, it would still take at least 30 JSOWs to cover

the desired 50 meter by 10 meter area to a thickness of half a meter. This would appear to be an inordinately large expenditure of munitions for the desired effect of putting a port facility out of action for a short period of time, meaning that the JSOW will likely not be the optimum delivery method, a determination that is compounded by its apparent inability to handle anything like the subsurface portion of the system.

Delivery Method 2: AGM-158 Joint Air-to-Surface Standoff Missile (JASSM)

Like the JSOW, the JASSM offers excellent standoff range, in this case nearly 200 miles, and is compatible with most of the Air Force's fighter and bomber aircraft. Unlike the JSOW, though, it incorporates a 1,000 pound (450 kilogram) warhead.[25] Though the JSOW could likely incorporate the liquid payload more readily with its submunitions-capable design, the JASSM may offer superior results with a much smaller expenditure of weapons, assuming that it could be converted to carry Slimeball components and could effectively dispense them upon arrival.

As previously mentioned, the assumed density of the foam agent in the Slimeball is roughly that of water, meaning that a 450 kilogram payload would translate into 450,000 cubic centimeters. This compares quite favorably to the JSOW, which only carried 82,000 cubic centimeters, and the end results are in keeping with these proportions. With the same assumptions of expansion, the number of JASSMs necessary to cover the 50 meter by 10 meter area dips by a factor of about five, and requires only six weapons to accomplish the same results that took 30 JSOWs to accomplish. The key to the success of this method will be the conversion of the warhead from an explosive to a liquid, but one can see the advantages in scalability that such a delivery method would have over submunitions. Each JASSM, or more generally each 450 kilogram/450,000 cubic centimeter warhead, can theoretically deliver enough material to cover an area just under 10 meters by 10 meters to a thickness of half a meter (which would

mathematically require 500,000 cubic centimeters). Recognizing this, planners could tailor the expenditure of weapons to the specifications of the facility that they wished to hit. If, for example, the width of the channel they wished to block were only 40 meters across, then the precise placement of about five 1,000 pound Slimeball rounds at 8 meter intervals could conceivably get the job done. Similarly, if a very small space was the target, say 10 meters across, then the foam could be adjusted to fill the space to a greater depth in order to present a more formidable barrier by placing multiple 1,000 pound Slimeballs in the same place. Conceptualized in this way, the advantages of the single large warhead begin to stand out when compared to the submunition method.

Delivery Method 3: GBU-32/31 Joint Direct Attack Munition (JDAM)

The GBU-32 JDAM, also featuring a 1,000 pound warhead, offers all the same advantages described with the JASSM, with the exception of standoff range – whereas the JASSM offers up to 200 miles, the JDAM's standoff range is limited to about 15 miles. JDAMs offer a similar wide variety of aircraft that can employ them, plus the significant advantage of possibly being employed on the unmanned MQ-9 Reaper in the future.[26] Additionally, the simple ubiquity of the system throughout the Air Force should ensure its availability and ease of employment.

Mathematically, the 2,000 pound warhead on the GBU-31 JDAM should be able to deliver twice as much foaming material. Depending on the fuzing, this could either cover twice as much area as the GBU-32's 1,000 pound warhead, or it could cover the same area but provide twice the depth. However, the GBU-31 is the first delivery platform considered so far that could conceivably carry the subsurface portion of the Slimeball in an effective form. As mentioned in the assumptions, the goal of the subsurface portion is to create a glob approximately 10 meters

across, due to the neutral buoyancy of the PAM gel and the subsequent need to fill the channel. Fortunately, we are not dealing with a *cube* that measures 10 meters on each edge, since this would be well beyond the carrying capacity of the GBU-31. However, a *sphere* 10 meters across has a volume of approximately 523 cubic meters, using the standard formula of [(4/3)(pi)(radius, cubed)]. Using the standard metric conversion, a cubic meter of water weighs 1,000 kilograms, and therefore the weight of the water contained in the sphere would add up to 523,000 kilograms. Using the assumed PAM absorption factor of 200 times its weight, it would be necessary to drop over 2,600 kilograms, or approximately three times the payload of the GBU-31, to create a 10-meter glob. In the absence of a breakthrough in materials, this is obviously outside of the realm of reasonable expectations. However, if you reduce the value of the radius to three and a half meters (resulting in a glob seven meters across, which would lurk only 3 meters, or about 10 feet, below the surface of the water), then the same mathematical process reveals that just under 900 kilograms of PAM is needed, which is nearly equivalent to the 2,000 pound warhead. Though this would not appear to be the optimal solution, it is at least a possible solution, and one that could conceivably be used in a cumulative manner not unlike the employment of the surface foam barriers.

Delivery Method 4: BLU-82 "Daisy Cutter"

Few military instruments are more blunt than the massive BLU-82, a bomb most famously used to clear helicopter landing zones in Vietnam. However, in light of its enormous capacity of 12,600 pounds, or about 5,670 kilograms, its advantages in employing the Slimeball quickly become apparent.[27] Mathematically, as might be expected, it has approximately 12 times the capacity of either of the 1,000 pound/450 kilogram warheads previously reviewed. Thus, the BLU-82 can deliver the desired 250 cubic meter barrier (50 meters by 10 meters by .5 meter) of

foaming material in a single shot with plenty of room to spare, and if completely filled, it could deliver twice that amount, thereby covering an area twice as large as our desired barrier, or filling it twice as deep to a depth of a full meter. Assuming that each weapon could be tailored to the target at hand, then this configuration is only one of three different potential configurations available to planners. If the target called for a greater concentration of subsurface barriers, then the BLU-82 could comfortably fit enough PAM to create two separate 10-meter globs, and could in fact hold nearly enough to create two 11-meter globs, giving an adversary something to think about as he considers running his ship over a mysterious mass that projects a few feet above the surface of the water. Or, as a final option, the weapon could potentially be loaded with both the surface and the subsurface materials simultaneously.

Unfortunately, there are a few drawbacks to the BLU-82, all of which have to do with its enormous size. It can only be dropped by an MC-130 cargo plane using a disposable dolly and parachute assembly to deploy it. In a benign environment, this would not necessarily be a problem, but air supremacy cannot always be taken for granted in any situation where a Slimeball may be dropped. Also due to the mechanics of its employment, it is inherently less accurate than most other systems. This is not much of a problem when it is armed with 6 tons of high explosives, but precision will be far more important in this scenario. With no onboard guidance and no means of correcting a weapon that is off-target, the BLU-82 Slimeball could easily end up well away from its desired aimpoint, thus reducing or eliminating its effectiveness.

This presentation of four possible delivery methods is not meant to be exhaustive or even to recommend a one-size-fits-all delivery system. Rather, based on the advantages and disadvantages of each, it would appear prudent to configure more than one for potential future

use, depending on the characteristics of the target that is to be engaged. The relative merits of each system should become apparent in the next section.

The Slimeball's Potential Targets and Employment Scenarios

When and under what circumstances could a Slimeball be successfully employed? Several factors would have to enter into any decision, including: the nature of the provocation or potential threat; whether or not U.S. forces have air supremacy; the potential for escalation or reprisals; the availability of adequate ordnance and delivery platforms; and preferably solid, actionable intelligence indicating the emergent nature of the threat, among other considerations. Ultimately, the commander will have to determine if sufficient advantages can be gained to offset any potential costs, whether in material, economic, or political terms. With these various factors in mind, three potential targets will be explored in this section; however, this is not meant to be a specific recommendation for attacking these particular facilities. They have been selected for their relevance to current and likely future conflicts and are meant to represent archetypical port facilities in their respective areas, from which a particular kind of threat could emerge.

Proposed Target 1: Boossaaso, Somalia

Though they have always been present in the Horn of Africa and its surrounding waters, the daring of Somalia's pirates has become particularly pronounced in the last couple of years. In a country with little functioning economy and even less regard for civil authority, piracy has mushroomed in the trade routes of the Gulf of Aden and the Indian Ocean. On the long, barren northern Somali coast, the port of Boossaaso marks one of the few established ports capable of serving ocean-going vessels. Sheltered behind a riprap wall some 400 meters offshore sits a protected inner harbor, measuring approximately 100 meters by 200 meters and accessed by an 40 meter-wide passage to the small bay. The harbor is home to dozens of fishing boats and

skiffs, along with a few larger commercial vessels of 20-30 meters in length. It should be noted that pirate vessels do not need to be of a particular size or character – anything capable of carrying a few men alongside a slow-moving target is adequate.[28] Nor, for that matter, do Somalia's pirates depend on established port facilities, often operating directly off the beach in remote areas. However, as the locus of maritime activity on one of the most lawless stretches of ocean in the world, Boossaaso certainly would provide planners with a tempting target.

Due to the almost complete lack of an air defense threat in the area, standoff range would not need to be an overriding concern. With the way clear, the BLU-82 Slimeball is a natural for employment in this scenario, in either of two configurations. Given the narrow 40-meter passage between the inner harbor and the bay, a single BLU-82 can either lay a half-meter thick foam barrier across the entrance along with a submerged 10- to 11-meter sphere, or can forego the subsurface barrier and lay twice as much foam. The latter seems to be a better choice, since the shallow draft of most of the vessels in the harbor would give them the flexibility to maneuver around the sphere (which would still cover less than a third of the passage), compounded by the impassability of a meter-thick barrier when viewed from vessels with low freeboards like the small boats used by the pirates. Additionally, some of the BLU-82's inherent inaccuracy is mitigated in the restricted waters of Boossaaso's bay and harbor – even if it were to strike several meters away from its intended aim point, it would still restrict movement in much of the harbor and even in the bay beyond due to their small size.

Boossaaso represents a unique combination of low air threat, high naval threat, egregious ongoing provocations, and marginal retaliatory strength, making it an excellent candidate to receive the largest non-lethal weapon ever conceived, the BLU-82 Slimeball.

Proposed Target 2: Bandar Abbas, Iran

Sheltered by Qeshm Island in the middle of the Strait of Hormuz, one of the most strategically important waterways in the world, the area around the Iranian city of Bandar Abbas is home to numerous cargo and civil maritime ports, and is the home for much of Iran's navy. This tightly constrained strait carries a significant percentage of the world's oil and has been the site of numerous at-sea provocations for decades. Notably, in January 2008, the USS *Hopper* (DDG 70) and USS *Port Royal* (CG 73) reported that they were confronted in the strait by five small boats from Iran that approached their ships in an aggressive manner. While the Slimeball would not have been of immediate assistance to the ships at the time, this episode highlights one of the most difficult and dangerous tactics that Iran can muster against U.S. and Coalition naval vessels, the swarm. It also illustrates the limited range of options that are available to local commanders in such circumstances, as well as the absence of any effective means to redress the situation. Captain David Adler of the *Port Royal* described the options available to him as limited to radio queries and warnings on the ship's whistle, while Captain Jeffrey James of the *Hopper* said, "We gave them every opportunity to break off, so that we didn't have to go the ultimate, which would have been deadly force."[29] Fortunately, this incident ended without an exchange of hostile fire, but the circumstances appear to call for some middle ground between token measures and actions that could touch off a much larger conflict in a region where tensions are high and relationships strained.

The development of the Slimeball would provide the U.S. with additional options and could change the tactical calculus of Iranian decision makers if they were aware that their ports could be targeted. The coast around Bandar Abbas, including the islands in the strait, contains a number of port facilities upon which the Slimeball could be effectively used. It is common

practice for the Iranian Revolutionary Guard Corps Navy (IRGCN), which bears primary responsibility for Iran's growing fleet of small boats, to house them up and down the coast in small ports to complicate targeting and ensure the fleet's survivability. In response to an aggressive incident such as the one described here, it may be deemed appropriate to respond by halting activity at a known IRGCN base in the region. While provocative, such a measure would do no permanent damage to the facility or the ships housed within it, and would surely influence the decision making in the future.

The typical configuration of the ports in the area involves the use of jetties built perpendicular to the coastline, often in pairs that curve towards each other to enclose a basin, or from which other jetties radiate to achieve the same thing farther from shore. Two such facilities, barely a kilometer apart, are present just off the corniche in downtown Bandar Abbas. The mouths of these harbors are somewhat wider than the one described in Somalia, and tend to be between 80 and 90 meters across, which is greater than any single weapon could effectively cover. The cumulative effects of multiple 1,000 pound Slimeball warheads, however, if accurately placed, could cover much if not all of the harbor entrances with between 5 and 8 weapons. Unfortunately, even in close proximity to the shore, the 15-mile range of a JDAM is probably inadequate to reach the desired aimpoint, notwithstanding the conventions restricting the operation of aircraft while transiting the strait itself (though in extreme circumstances, both of these limitations could be disregarded in the interest of protecting our forces). If the JDAM's range is indeed too short, then the choice of weapon would become the JASSM, which could be launched from nearly 200 miles away and could potentially avoid detection due to its stealthy design.

Iran, not without reason, would surely see such an action as hostile and could very well retaliate in some manner, though the incident could pass without escalation as Iran sizes up the situation. The choice of port is important and should be selected based on the presence of IRGCN assets while avoiding as many of Iran's commercial, fishing, tanker, and regular Navy assets as possible. The goal is to temporarily put a facility out of action, and by studiously avoiding units and capabilities that are not involved, we can demonstrate not only our resolve but our precision as well. Properly telegraphed and justified, such an attack could very well provide the benefit of less provocative behavior, and possibly less activity altogether, when U.S. and Coalition vessels transit the strait.

Proposed Target 3: Sanya, Hainan Island, China

With much media fanfare, the existence of an underground submarine base at Sanya on China's Hainan Island was publicized in 2008. The base is situated amidst additional piers and shore facilities, all of which rests behind an impressive chain of breakwaters to provide safe harbor for the complex. The fact that China uses underground facilities to house some of its submarines has been known for some time, but the scale of the Sanya project appears to dwarf previous efforts, and may be capable of sheltering up to 20 submarines in a cavern at least 60 feet high.[30] The location of the facility, in China's southernmost province, also suggests intent to establish a naval presence throughout the South China Sea and beyond into the Pacific and Indian Oceans, with the potential to wield destabilizing influence on some of the most heavily travelled trade routes in the world.

Any number of situations can be envisioned in which it would be advantageous to the United States to be able to sideline such a capability, whether in support of Taiwan, to defend vital strategic and economic sea lines of communication through the South China Sea, or perhaps

to defuse a territorial conflict over disputed territories in the region like the Spratly Islands or Paracel Islands. In any of these circumstances, it would benefit the U.S. to have the ability to act in a definitive fashion but in a manner that does not necessarily elevate the hostilities to a broader conventional conflict. The use of non-lethal and temporary measures, like the Slimeball, could provide just enough time or breathing room to take control of a situation that threatened to spin out of control.

As the United States learned in no uncertain terms in the April 2001 incident near Hainan Island involving an American EP-3 and a Chinese fighter, China is very protective of its airspace and will challenge aircraft that come within areas that it claims as its own, even if that claim is not recognized by other parties. In other words, the 15-mile range of a JDAM is entirely too short to be employed in this scenario, leaving the JASSM as the logical choice. As was the case with Iran, its 200-mile standoff range and its stealthy characteristics give it the best chance of successfully reaching its target, in this case the 25-meter-wide entrance to the Sanya submarine base. The careful placement of no more than three JASSMs would effectively cover the entire width of the entrance, though due to the nature of the facility and the vessels it shelters, a single shot might have a dissuasive effect – after all, with such a narrow entrance and no way around, the 10-meter-wide barrier that the JASSM could produce might be sufficient. Or, conversely, it may be advisable to place multiple rounds on target to completely cover the width of the entrance and even to build it up thicker than the planned half meter, though filling the mouth of the cavern entirely (approximately 600 square meters) would appear to be impossible. Finally, even though this situation would potentially benefit the most from the application of the subsurface portion of the Slimeball, no method discussed here would be capable of delivering it

to the target due to the limited range and the near certainly that any platform attempting to hit the target would be intercepted.

As with the Iranian scenario, the risk of reprisals is very real and must be taken into consideration by planners, but in a situation that shows signs of escalating to a conventional exchange for control of territory or sea lanes, having the ability to take action that does not cross the threshold of deadly force could provide the opportunity for the belligerents to reconsider the gravity of their actions.

Conclusions

There are some unanswered questions regarding the Slimeball's performance that have not been addressed here, mostly because it would require testing and evaluation in real-world conditions to determine the answers; for example, will the subsurface portion be anything more than a squishy bag full of harmless gel, or will it actually impede a ship that attempts to overcome it?[31] An exhaustive survey of the myriad considerations involved with the development of the system is necessary as the effort proceeds, but is impossible here.

Not every weapons system is a good idea, and not every good idea should become a weapons system. There is no shortage of brilliant concepts that didn't make it, or of mediocre ones that did. In judging the Slimeball concept, then, it seems appropriate to comment upon it on four different levels – feasibility, advisability, deliverability, and applicability.

Feasibility: There is no single element of the Slimeball that doesn't exist or cannot be used in the manner described. Scientific research into various compositions and applications of foam has a long history, and none of the proposed surface foam barrier's specifications (density, desired expansion, stickiness, or limited perseverance) is beyond the realm of possibility. The greatest leap in the formulation, ironically, is in the application of the material that touched off

the whole idea, rheopectic fluids. Research has not produced any information on rheopectic foam; however, it seems that the rheopectic fluid itself is not made into foam, but rather is incorporated in the formula along with the foaming agent. As long as the fluid retained its rheopectic properties, then it should work as described here. Likewise, the concept behind the subsurface barrier composed of polyacrylamide (PAM) does not involve anything that must be invented, and only presents physical challenges regarding delivery and keeping the material in place. It is also not unreasonable to believe that an advanced version of the material could be developed that would offer greater absorption rates than the factor of 200 that is used here, and therefore would offer better performance in real-world usage situations. In short, it can be done.

Advisability: The meaning here is, is this concept in accordance with strategic guidance and commanders' intent? The 1996 non-lethal weapons guidance specifically called for development and employment of weapons that do not depend on physical destruction, and preferably that had reversible effects, both of which are satisfied by this concept. Additionally, the pattern of development in this arena has moved from small targets and individuals, moving up to groups and mobility targets, and recently expanding into the maritime domain. The Slimeball therefore could be regarded as simply one of the natural next steps in the development process.

The world has not stood still since 1996, however. In some ways a concept like this one appears to be more advisable than ever, considering the focus on small wars, insurgencies, and asymmetric warfare, all under the scrutiny of increasingly ubiquitous media. Arguing against the development of such a weapon, on the other hand, are a variety of legal concerns, such as: whether or not the development and use of the Slimeball violate the Chemical Weapons Convention; whether or not its employment constitutes an act of war; and whether or not it

violates the principles innocent passage or transit passage when fired from within a target country's territorial waters or exclusive economic zone. Another potential point of contention is environmental concerns, since no matter how benign the ingredients can be made, there will inevitably be questions raised about the long term effects on the target, sea life, local ecosystems, and more. It must be acknowledged that the costs of defending the use of such a system may outweigh the benefits that could be gained by it, whether the manifold objections to it are justified or not.

Deliverability: Here, it seems clear that the existing array of weapons systems and delivery platforms are adequate for putting the Slimeball on target, especially the foam surface barrier. This assumes that existing systems can be modified to carry the Slimeball payload instead of conventional explosive warheads and that they could effectively distribute it when they arrived at the target, but none of these considerations seems to be a show-stopping engineering challenge. Much like the composition of the Slimeball itself, the deliverability challenge appears to be in combining existing systems and technology in a new fashion, rather than having to come up with something completely from scratch. Additionally, with advances in materials research and development, it is entirely possible that the system will become easier to put on target, depending on advancements made in foam compression and expansion, and better absorption performance by the subsurface component.

However, in spite of this, the systems that appear best suited are not particularly common or widely distributed. Total quantities of JASSMs in the inventory can be measured in the thousands[32] and BLU-82s in the hundreds or less,[33] whereas JDAMs number in the hundreds of thousands and are much cheaper to boot.[34] These arguments notwithstanding, the conclusion is similar to that made above: it can be done.

Applicability: The meaning here is simple – will the Slimeball have the desired effect once it has been put on target? This, of course, is almost impossible to determine since it will vary in each potential target and each adversary. Somali pirates may shrug it off entirely, may take the day off, or may simply launch from the beach nearby in a different vessel. Iran may call a halt to its aggressive activity in the strait, may redouble its harassment campaign, or may use the Slimeball attack to lambaste the United States in the media. China may declare the attack to be of no consequence, may step back from its bullying for political advantage, or may declare it an act of war and mobilize additional forces as a prelude to a conventional war. These outcomes, and many others, must be considered when deciding to employ military force against an adversary to achieve a desirable end state, but two things remain clear: there are costs associated with any course of action, even if that course of action is to do nothing; and providing a decision maker with more options is generally preferable to fewer options, especially if it provides as alternative to stark either/or propositions. The continued development of non-lethal weapons across domains gives a commander choices which may be applicable in any number of potential situations, which is surely in keeping with the never ending pursuit of our national interests.

Notes

[1] Mercogliano, 8.
[2] AFDD 2-1.4, 7.
[3] DoD Directive 3000.3, 2.
[4] Joint Non-Lethal Weapons Program, 10 April 2008.
[5] Joint Non-Lethal Weapons Program, 10 April 2008.
[6] Davison, "The Contemporary Development of Non-Lethal Weapons," 18.
[7] Bowen, January 2009.
[8] Collins, Edgewood Arsenal, e-mail to author, 5 November 2008.
[9] Collins, Edgewood Arsenal, e-mail to author, 5 November 2008.
[10] Collins, Edgewood Arsenal, e-mail to author, 21 November 2008.
[11] Hambling, 7 March 2006.
[12] Mazzarra, Penn State University, e-mail to author, 13 October 2008.
[13] Alexander, 70.
[14] Alexander, 78.
[15] Mazzarra, Penn State University, e-mail to author, 13 October 2008.
[16] Goolsby, 5.
[17] Brown, 2.
[18] Ruckenstein and Bhakta, 4134.
[19] Swearingen, Cole-Parmer Technical Library.
[20] Collins, Edgewood Arsenal, e-mail to author, 21 November 2008.
[21] Collins, Edgewood Arsenal, e-mail to author, 21 November 2008.
[22] Collins, Edgewood Arsenal, e-mail to author, 21 November 2008.
[23] "AGM-154 Joint Standoff Weapon," 28 August 2007.
[24] "BLU-97," 25 January 2009.
[25] "AGM 158 JASSM," 25 January 2009.
[26] "Joint Direct Attack Munition GBU-31/32/38," November 2007.
[27] "Bomb Live Unit 82/B Fact Sheet." National Museum of the USAF.
[28] Gettleman, A1.
[29] "Port Royal and Hopper COs Discuss Incident in Strait of Hormuz," 15 January 2008.
[30] Harding, 6 May 2008.
[31] Collins, Edgewood Arsenal, e-mail to author, 21 November 2008.
[32] "AGM 158 JASSM," 25 January 2009.
[33] "Bomb Live Unit 82/B Fact Sheet," National Museum of the USAF.
[34] "Joint Direct Attack Munition GBU-31/32/38," November 2007.

Bibliography

"AGM-154 Joint Standoff Weapon (JSOW)." United States Navy Fact File, 28 August 2007. http://www.navy.mil/navydata/fact_display.asp?cid=2100&tid=300&ct=2.

"AGM-158 JASSM." Deagel.com Guide to Military Equipment and Civil Aviation, 25 January 2009. http://www.deagel.com/Land-Attack-Cruise-Missiles/AGM-158A-JASSM_a001073001.aspx.

Air Force Doctrine Document 2-1.4. *Countersea Operations*. 4 June 1999.

Alexander, John B. *Future War: Non-Lethal Weapons in Twenty-First Century Warfare*. New York: St. Martin's Press, 1999.

Annati, Massimo. "Non-Lethal Weapons: Their Application in the Maritime World." *Naval Forces* 27:45-53 2006. http://web.ebscohost.com/ehost/pdf?vid=2&hid=14&sid=40306a48-7b2c-4688-a683-63591180 9820%40sessionmgr9.

Bickford, Lawrence, Project Manager, Edgewood Arsenal, Aberdeen Proving Grounds. To the author. E-mail, 14 October 2008.

"BLU-97." Deagel.com Guide to Military Equipment and Civil Aviation, 25 January 2009. http://www.deagel.com/Warheads/BLU-97-CEB_a000948001.aspx.

"Bomb Live Unit (BLU-82/B)" Fact Sheet. National Museum of the USAF. http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=1013.

Bowen, Jennifer. "Maritime Evaluation Assesses Non-Lethal Weapons." Joint Non-Lethal Weapons Program. 13 January 2009. https://www.jnlwp.com/misc/articles/fotm0109.pdf.

Brown, Harry Jr. et.al. "Stable Aqueous Foam Application, and Method of Use Thereof For Visual Obscuration and Area Denial." United States Patent 4,203, 974. 20 May 1980. http://www.aquafoam.com/patents/HB4203974.pdf.

Chemie.de Information Service. "Non-Newtonian Fluid." http://www.chemie.de/lexikon/e/Non-Newtonian_fluid/.

Collins, Kenneth, Project Manager, Edgewood Chemical/Biological Center, Aberdeen Proving Grounds. To the author. E-mail, 5 November 2008.

Collins, Kenneth, Project Manager, Edgewood Chemical/Biological Center, Aberdeen Proving Grounds. To the author. E-mail, 21 November 2008.

Collins, Kenneth, Project Manager, Edgewood Chemical/Biological Center, Aberdeen Proving Grounds. To the author. E-mail, 24 November 2008.

Council on Foreign Relations. “Lack of Nonlethal Weapons Capabilities Hindering U.S. Efforts in Postwar Iraq; Experts Urge Department of Defense to Increase Spending Seven-Fold.” 26 February 2004. http://www.cfr.org/publication.html?id=6794.

Davison, Neil. “The Early History of Non-Lethal Weapons.” Bradford Non-Lethal Weapons Research Project, Department of Peace Studies, University of Bradford UK, Occasional Paper No. 1, December 2006. http://www.bradford.ac.uk/acad/nlw/research_reports/docs/BNLWRP_OP1_Dec06.pdf .

Davison, Neil. “The Development of Non-Lethal Weapons in the 1990s.” Bradford non-Lethal Weapons Research Project, Department of Peace Studies, University of Bradford UK, Occasional Paper No. 2, March 2007. http://www.brad.ac.uk/acad/nlw/research_reports/docs/BNLWRP_OP2_Mar07.pdf.

Davison, Neil. “The Contemporary Development of Non-Lethal Weapons.” Bradford Non-Lethal Weapons Research Project, Department of Peace Studies, University of Bradford UK, Occasional Paper No. 3, May 2007. http://www.bradford.ac.uk/acad/nlw/research_reports/docs/BNLWRP_OP3_May07.pdf.

Defense Online. “Boeing Develops JDAM-Based Countermine Weapon for the US Navy.” 10 August 2008. http://www.defense-update.com/products/j/jabs.html.

Department of Defense (DoD) Directive 3000.3. *Policy for Non-Lethal Weapons,* 9 July 1996.

Gettleman, Jeffrey. “Somalia’s Pirates Flourish in a Lawless Nation.” *New York Times*, 31 October 2008, A1. http://www.nytimes.com/2008/10/31/world/africa/31pirates.html?pagewanted=1&_r=1.

Goolsby, Tommy D. “Aqueous Foam as a Less-Than-Lethal Technology for Prison Applications.” Sandia National Laboratory, 1997. http://www.aquafoam.com/papers/Goolsby1.pdf.

Grzeskowiak, Marie and Vany Covindane. “Polymer Melt State Behavior.” Seminar. Tampere (Finland) University of Technology. http://www.tut.fi/plastics/liitteet/MOL-6936/Melt%20state%20behaviour.pdf.

Haghshenass, Fariborz. “Iran’s Asymmetric Naval Warfare.” Washington Institute Policy Focus #87, September 2008.

Hambling, David. “Sticky Foam Gets Serious.” DefenseTech.org. 7 March 2006, http://www.defensetech.org/archives/002220.html.

Hambling, David, “US Weapons Research Raises a Stink.” Guardian.co.uk. 10 July 2008. http://www.guardian.co.uk/science/2008/jul/10/weaponstechnology.research.

Harding, Thomas. "Chinese Nuclear Submarine Base." Telegraph.co.uk. 6 May 2008. http://www.telegraph.co.uk/news/majornews/1917167/Chinese-build-secret-nuclear-submarine-base.html.

"Joint Direct Attack Munition GBU-31/32/38" Fact Sheet. Air Force Link, November 2007. http://www.af.mil/factsheets/factsheet.asp?id=108.

Joint Non-Lethal Weapons Program. "Current Non-Lethal Capabilities." 10 April 2008. https://www.jnlwp.com/current.asp.

"Joint Stand-Off Weapon." *Defense Update* International Online Defense Magazine, 16 October 2006. http://www.defense-update.com/products/j/jsow.htm.

Mazzara, Andrew, Director, Institute for Non-Lethal Defense Technologies, Penn State University. To the author. E-mail, 13 October 2008.

Mercogliano, Salvatore. "The Container Revolution." *Sea History* 114: 8-11, Spring 2006.

Nisbett, Donald A. "Airpower's Emasculation?: Non-Lethal Weapons in Joint Urban Operations." Newport, RI, Naval War College, 2005. 26 p. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA464450&Location=U2&doc=GetTRDoc.pdf.

North Atlantic Treaty Organisation and Research and Technology Organisation. "The Human Effects of Non-Lethal Technologies." August 2006. http://ftp.rta.nato.int/public//PubFullText/RTO/TR/RTO-TR-HFM-073/$$TR-HFM-073-ALL.pdf.

Pan, Esther. "Defense: Non-Lethal Weapons." Council on Foreign Relations. 27 February 2004. http://www.cfr.org/publication.html?id=7750#8.

Parsch, Andreas. "Raytheon (Texas Instruments) AGM-154 JSOW." Directory of U.S. Rockets and Missiles, 24 May 2007. http://www.designation-systems.net/dusrm/m-154.html.

"*Port Royal* and *Hopper* COs Discuss Incident In Strait of Hormuz." Commander, U.S. Naval Forces Central Command, U.S. Fifth Fleet, Combined Maritime Forces, 15 January 2008. http://www.cusnc.navy.mil/articles/2008/007.html.

Ruckenstein, Eli and Ashok Bhakta. "Effect of Surfactant and Salt Concentrations on the Drainage and Collapse of Foams Involving Ionic Surfactants." *Langmuir* 12: 4134-4144, 21 August 1996. http://pubs.acs.org/doi/abs/10.1021/la960193x.

"Secret Sanya – China's New Nuclear Naval Base Revealed." Jane's, 21 April 2008. http://www.janes.com/news/security/jir/jir080421_1_n.shtml.

Swearingen, Corte. "Velocity-Profile Deviations Influence Flowmeter Performance." Cole-Parmer Technical Library. http://cole-palmer.com/techinfo/techinfo.asp?htmlfile=V_PDeviations.htm.

United States Joint Forces Command Joint Warfighting Center. Joint Doctrine Series Pamphlet 2, "Doctrinal Implications of Low Collateral Damage Capabilities." Suffolk, VA, Joint Forces Command, Joint Warfighting Center, January 27, 2003. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA423986&Location=U2&doc=GetTRDoc.pdf

Washington Times. "Commercial Photos Show Chinese Nuke Buildup." 16 February 2006. http://www.washingtontimes.com/news/2006/feb/16/20060216-020211-7960r/.